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DEVELOPMENTS IN AUTOMATIC VEHICLE IDENTIFICATION DURING 1974 AND 1975

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Abstract

Technology for automatically and uniquely identifying vehicles in motion has been under development and test since the early 1960's, and is receiving increasing attention. Systems using this technology could enable non-stop collection of tolls and other road user charges, with the charge dependant on time, place or other condition of use. Other potential applications include traffic control, law enforcement and fleet management.

This report summarizes recent developments leading to these and other applications. A coding format has been developed which is suitable for standard use. An "intermediate" generation of radio frequency equipment did not perform as expected, but a new generation is about to start tests. A system using microwave is being developed and tested. An optical system is delivering good performance in conjunction with reduced rate cash toll collection. Studies of cost elements in a non-stop toll collection system, such as account maintenance, are being conducted. Market research is underway.

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DEVELOPMENTS IN AUTOMATIC VEHICLE IDENTIFICATION DURING 1974 AND 1975

CONTENTS

Summary 1

Background 3

Port Authority Test Status 8

General Electric Development 13

New Jersey Turnpike Studies 15

System Cost Analysis 18

Further AVI Equipment Developments 21

Road Pricing 24

Vehicle Monitoring 25

Railroad Developments 27

IBTTA Developments 29

Appendix

References

List of AVI Suppliers

Discussion of Coding Format

Layout of AVI Data Code

Description of AVI Data Code

Picture of Microwave Transponder

DEVELOPMENTS IN AUTOMATIC VEHICLE IDENTIFICATION

DURING 1974 AND 1975

Summary

By the end of 1973 several reports (References 1-5,8,16) were published describing the growth since 1963 of technology for identifying vehicles uniquely and automatically while they were in motion. This could enable fully automatic non-stop collection of tolls and other road user charges such as parking fees, as well as assist traffic operations, vehicle security, law enforcement, vehicle maintenance, fleet management, motor vehicle administration, transportation planning and other functions.

With the co-sponsorship of the International Bridge Tunnel and Turnpike Association (IBTTA) and the Federal Highway Administration (FHWA), an "Organizing Conference on Automatic Vehicle Identification" was held in Washington D.C. on September 17, 1973. The Conference was attended by 156 registrants representing over forty agencies, companies and associations. A "Summary Report" is available (Reference 6). IBTTA members last received a comprehensive report on the development of Automatic Vehicle Identification (AVI), at the 1973 Annual Meeting in Miami Beach (Reference 7). This paper summarizes developments since then.

Since the end of 1973 there has been both progress and setback. The general rule on development of a new system as complex as this is two steps forward and one step back. Without counting, it seems AVI has followed this general rule during the past two years.

The major steps forward include success by the Port Authority in specifying, bidding, purchasing, and initial testing of a new AVI system; success by General Electric in selling, building and delivering for PA test a new generation of low power radio frequency AVI equipment; success by Fairchild Electronics in demonstrating and receiving a second stage development contract from the U. S. Department of Defense for a microwave AVI system; the decision by the New Jersey Turnpike Authority to invite proposals and award contracts for demonstration of two additional AVI systems; and decision by the Association of American Railroads to study a new generation of Automatic Car Identification equipment. And while it is not presently being used as a stand-alone system for non-stop automatic toll collection, another success has been the use of an optical sticker in conjunction with coin/token collection at the Delaware River Port Authority bridges in Philadelphia.

On the other hand, the General Electric AVI equipment under test at the Golden Gate Bridge and the Port

Authority Bus Terminal did not meet expectations. This equipment, of a design later than that tested successfully by the Port Authority under contract for the U. S. Department of Transportation, failed because of breaks in a wire connecting a component to a printed circuit board, caused by different coefficients of thermal expansion. This made it impossible for the staff of the Golden Gate Bridge to offer the AVI system to the general public, as had been planned. However a new contract has now been negotiated between the Golden Gate and GE officials, providing continued testing of the latest GE design as developed to meet the Port Authority contract.

In summary, progress has been made: interest in AVI for non-stop toll collection has continued, and the outlook is for field testing and refinement of several forms of AVI for toll collection in the immediate future.

Background

In view of the continuing growth of interest in this field however, a brief review of AVI may help here.

Why should members of the toll road industry be particularly interested in AVI? The ability of this technology to automatically and uniquely identify moving vehicles can, with other system components which have already been proven, enable fully automatic collection of tolls. That is, collection without requiring the transfer of any physical medium of currency, and therefore without requiring any action on the part either of the motorist or the toll agency. This means toll collection without toll collectors, and without toll plazas, in its ultimate form. And that provides benefits for patrons in safety and convenience, as well as for toll agencies in lower costs and higher security. In addition, AVI can provide other benefits such as in road use and traffic control, in vehicle administration and road planning.

What is AVI? This technology is part of a broad field created in the last ten to fifteen years and now finding application in supermarkets, clothing stores and other retail outlets, as well as in military and transportation operations. Typically there are two elements involved - a sticker or other passive device carried on the vehicle or object to be identified; and an active element mounted in or near the roadway and capable of reading electronically the identity of the device on the vehicle. Generally the vehicle-mounted device is referred to as a "transponder"; the road device as an "interrogator". Depending on the type of system, information may be transferred between the transponder and the interrogator in the visible light spectrum, in the radio frequency spectrum, or in the microwave spectrum. Energy required for the transponder to emit its identity can be supplied by an internal power source such as batteries; by the electrical system of the host vehicle; or by reflectance or inductance from the interrogator power source.

How can this technology be used in a non-stop toll collection system? Since the only transfer at the time of vehicle passage is of electronic information, cash payment must be made either before or after the vehicle uses the toll facility. In either case it will be necessary to maintain an account for each vehicle (or fleet operator), and update the account after each use and each payment. The amount of bookkeeping this entails would not be feasible without recent advances in computer technology. And while such accounting is within the state of the art in computers today, the cost may still be excessive in some toll applications. A key factor in reducing costs is the use of standard transponders and interrogators, and possibly a pooled accounting operation. With standardization, the motorist can use his tranponder at the facilities of many toll and other agencies. And with standardization, each toll operator can handle a larger proportion of toll collection through AVI. Standardization provides the ability to read any transponder with any interrogator, and requires standard message format and coding as well as standard AVI hardware.

Who are the principal suppliers of AVI? A list of some of the most active companies is attached to this report, but as far as is known at this point only five companies are actively marketing AVI systems. These are General Electric, North American Phillips and Glenayre Electronics for the radio frequency system; and Computer Identics and Identicon for the optical system. In addition, Fairchild Electronics is moving to the marketing stage with a microwave system, and RCA has also announced a microwave system. Wabco demonstrated successfully a radio frequency system, but their present marketing plans are not known. Representatives of other companies marketing or planning to market an AVI system which are not listed on the attachment are invited to contact the author for inclusion on future lists.

Where are AVI developments taking place? Both the potential suppliers and potential agency users come from nearly all industrial countries. There has been significant development in France, the Netherlands, Great Britain, Germany, Canada and Japan as well as in the United States. The most significant field testing of radio frequency systems has been at the Golden Gate Bridge in San Francisco, and at the Port Authority of New York and New Jersey. During 1972 and 1973 the Port Authority conducted a Federally sponsored test (Reference 5) which confirmed radio frequency AVI performs at the 98% plus level of accuracy needed for use in a fully automatic AVI-based toll system. Optical systems were tested briefly at the Quebec Autoroutes and at the New Jersey Highway Authority, and now are being used in conjunction with a coin system at the Delaware River Port Authority bridges in Philadelphia.

When will AVI be in widespread use? The answer depends on many developments. However it seems likely the first major offering to the public of a fully automatic non-stop AVI-based toll collection system will take place in the next five years. The Golden Gate Bridge had planned to offer such a system last year, but the performance of the General Electric hardware caused them to defer this introduction. The New Jersey Turnpike may offer such a system on a test basis in the next year. And the Port Authority is working to implement an AVI system for buses in the next year. While the rate of public acceptance depends first on the decision by toll agencies to offer such systems, second on the performance of the systems and third on the actual costs and benefits, it remains increasingly likely these factors will become well defined in the next five years.

Port Authority Test Status

When the most recent status report was prepared, in November, 1973, bids had just been received by the Port Authority from the four suppliers of radio frequency AVI systems tested extensively by the Port Authority in a program supported by the Federal Highway Administration. The low bidder was General Electric, and during much of 1974 the main work was to contract with GE for supply of the proposed system. This involved obtaining final authority from the Port Authority management to proceed with the test, and definition of several contractual provisions as well as extensive technical consultation with GE. Approval was given to enter a contract on February 15, 1974, and the contract was finally signed on September 10, 1974. The main source of delay in signing the contract related to legal problems, rather than technical aspects of the equipment.

While a specification for AVI was developed and included in the detailed report "Automatic Bus Identification" submitted by the Port Authority to the Federal Highway Administration (Reference 5), further attention was given to the coding and message format. These are critical aspects in assuring the tested system could serve as a standard for the toll industry.

The format adopted after consultation with General Electric staff assumed an 80 bit transponder, which would be coded in two main forms. One form would be for transponders containing only fixed numbers - that is, all bits in the transponder would be coded at time of manufacture and could not be altered subsequently without destroying the transponder. The second form provided, in addition to some fixed numbers, five decimal digits of number capacity which could be varied from on board the vehicle. While the main market of concern to the toll road industry is assumed to be with transponders which are coded permanently, it was desired to test some of the variable units which may be particularly valuable for fleet operators. For example, buses could display route number and passenger loading to assist dispatchers optimize fleet use.

The coding selected for this application places heavy emphasis on accuracy and reliability. The Port Authority research staff is concerned with the high cost of servicing inaccurate data in a toll application, and believes that over the fifteen year life of transponders the risk of decay in reliability is sufficiently large as to justify the most stringent attempts in information coding to assure accurate data.

Accordingly two error codes have been incorporated in the transponders to be tested by the Port Authority. In addition to the standard 2 out of 5 code, a special type of cyclic error detection code named BCH (the last initials of its three inventors) was incorporated. The BCH code provides not only for the detection of bit errors, but in many instances also allows for correcting them. The particular BCH code incorporated in the new Port Authority transponders allows for detecting up to a four-bit error, and correcting up to a two-bit error. Fourteen of the 80 bits available in the transponder layout are dedicated to carrying the BCH code. Using both the BCH and 2 out of 5 codes guarantees that all errors of four bits or less, and all odd number of bit errors, will be detected. Errors involving two bits or less can, in additon to being detected, be corrected.

More detailed discussion of the coding format is given in the Appendix.

An important feature of the test planned early in 1974 was joint participation with the New Jersey Turnpike Authority, both to broaden the coverage of the test and to explore inter-agency coordination in AVI operation. With this approach, the Turnpike Authority would obtain 250 of the fixed transponders, and the Port Authority would obtain

100 of the fixed-plus-variable units. However the Turnpike Authority management eventually decided not to proceed with the GE test. The matter came before them for consideration when Turnpike traffic had been cut severely by the shortage of gasoline in the winter of 1974, which was an important factor in their decision. As a result, only the Port Authority-ordered 100 fixed-plus-variable transponders are to be tested under this program in the New York-New Jersey area. However transponders with all fixed data will be tested at the Golden Gate Bridge.

During design of the 80 bit transponder, General Electric made another decision which influences the Port Authority test. For economy in production, GE decided to standardize on a 60 bit card. The remaining "bits" needed to code the variable data would be supplied externally to the transponder, at the vehicle end of the cable connecting the transponder to whatever apparatus might eventually be used on the vehicle to enter variable data. The result of this decision is that the units to be tested by the Port Authority will be the same as those GE plans to market for fixed transponder applications.

The GE transponders and interrogators were delivered to the Port Authority in June through August, 1975. PA staff had previously installed loops for the interrogators in toll lanes 3 and 5 of the Lincoln Tunnel toll plaza in Weehawken, New Jersey. Also, cable had been run approximately 200 feet to a room overlooking the toll plaza where the interrogator circuitry could be located. Extensive support was provided by GE in placing the new system on-line, and the functioning of both the interrogator and transponder units has been demonstrated satisfactorily. The Port Authority staff has tested most transponders to assure proper operation, and initial units have been delivered to Transport of New Jersey, the bus company which has again agreed to participate in the test program.

The immediate aim now is to equip 40 of the TNJ buses with 80 new transponders, two to a bus. This initial test will enable cross-checking transponders, to insure instances where a transponder might fail completely will be detected. In addition, each bus is to retain one of the "intermediate generation" transponders. These units were supplied by GE following the Federally-sponsored test, and are the type which have not demonstrated adequate reliability. Nevertheless the remaining units of this type will provide insight into the travel time of buses between the Lincoln Tunnel toll plaza in New Jersey, and the Port Authority Bus Terminal in Manhattan where the "old" interrogator used in the Federal test has been maintained.

Information from both the new and old interrogators is to be routed to a computer at the Lincoln Tunnel Administration Building. The computer configuration includes a disc, and one of the main purposes of the test is to evaluate and demonstrate the feasibility of maintaining AVI accounts on-line.

In selecting the RF approach for this test, the Port Authority has not committed itself to this technology for the full system. Continuing interest is being maintained in alternate approaches, and additional testing may be scheduled.

General Electric Development

While there may have been many internal developments in the refinement and production of the latest AVI equipment, to the operating agency three developments are particularly important. One was the decision by GE staff to standardize on a 60 bit transponder, related in part to their decision against going at this stage to an integrated chip for the transponder logic. When a chip is designed, the information content could possibly be expanded at no additional cost for the transponder, though the cost to interrogate and process the extra information could be significant.

The area of main concern to a using agency, however, is the packaging of the GE transponder. Rather than encasing the transponder circuitry in a potting material, as was done with the "intermediate generation" of transponders which encountered reliability problems due to mechanical wiring failures, the latest model seals the transponder circuitry in a hard shell covering a foam material. This approach was tested by GE in a desert environment, and appears to have solved the problem. There has not been sufficient experience with the new transponders at the Port Authority to confirm their reliability. The outer dimension of the transponder is approximately the same as before, and the requirement for spacing the transponder approximately 4 inches from heavy metal on the vehicle is still in force. Therefore to the extent difficulty has been encountered in mounting transponders on small vehicles, as reported by the Golden Gate Bridge staff, such difficulties remain with the latest model. With the trend to small vehicles, this may become a more significant problem.

Thirdly, in designing the interrogator the GE engineers elected to use a microprocessor rather than hard-wired logic. This approach offers considerable flexibility during the testing stages, as adjustments to the interrogator logic can be incorporated relatively easily. In the limited testing accomplished to date, the microprocessor has functioned satisfactorily.

New Jersey Turnpike Studies

Although Turnpike management decided early in 1974 against proceeding with the General Electric test, continuing inflation in the cost of conventional toll collection has maintained their basic interest in new forms of automatic toll collection. After re-thinking their requirements, Turnpike staff recommended and received approval for solicitation of proposals for systems which would automatically identify patrons rather than vehicles. Their status in September, 1975 was summarized in a letter from Mr. Harry R. Loewengart, Project Engineer for the Turnpike, as follows:

> "About one year ago, we formulated a four year toll equipment modernization plan. This plan provides for development (where needed) and implementation of an overall system which includes, among other features, 'permanent identification' of commuter vehicles (instead of single use toll tickets), a computer network and prepayment or charging of tolls by about 100,000 patrons. (Cars constitute 85% of our traffic.)

"Even if satisfactory AVI equipment were available today, its usefulness would be very limited; before automatic vehicle identification can be put to large scale use, we need to automatically detect (and classify) vehicles. Since our toll classifications are substantially related to a vehicle's axle count, the 'missing link' is a reliable and accurate vehicle detector.

"As you know, we recently solicited proposals for vehicle identification and detection equipment from 35 firms. From the six responses, we have selected two - Fairchild's for a microwave system and Computer Identic's for an electro-optical system. A development and demonstration contract has been awarded to each; under these contracts both systems will be tested competitively in early 1976, with 100 participants (Authority staff).

"Both systems provide for a transponder or label which can be hand held or attached to the vehicle. We specify a seven character code, a six decimal digit account number, plus a CRC (cyclic redundancy character). This code will also be visibly displayed on the transponder or label as a backup in case of misread or failure and for use in lanes without VI

> equipment (keyboard entry of misread digit or of all digits, respectively). Both contracts provide for production drawings which can be competitively bid.
>
> "The interrogator/scanner is to include minimal digital electronics. Most of the digital processing will be done by the toll lane controller (a microprocessor) and the plaza computer (one per large plaza or grouping of small plazas, 24-30 lanes). We have six lanes converted to microprocessors, 24 more under contract; we plan to have all our lanes converted by early 1977."

In addition to exploring hardware for this system, the Turnpike staff is studying the "back office" costs of operating such an AVI system, and also planning a survey of Turnpike patrons to determine their interest in such new approaches to toll collection. The studies are still in progress, but are developing important new data which will be essential in applying AVI technology in the toll road industry.

System Cost Analysis

The cost of transponders is probably the most visible element in AVI system cost, because the ultimate system will deal with millions of vehicles. By far the least expensive tranponder is the optical sticker, with costs ranging from ten cents to eight dollars depending on the required information content, reliability and longevity. Cost of the radio frequency transponders is in the $50 range, and this is a significant drawback to widespread application at first glance. However the estimated life of these units, fifteen years, coupled with the greater accuracy, reliability and information capacity they offer as compared with optical stickers, may make them competitive in price per use. The cost of microwave transponders has not yet been defined, since none of these units has yet reached the market stage, but present indications are they would be midway between the optical and the radio frequency units.

To compare these technologies accurately however, it is essential to consider all costs associated with operating AVI-based toll systems using the respective technologies. For example, account maintenance could be a most important cost, and may depend significantly on the accuracy of the particular AVI technology used.

A preliminary analysis of total system costs was made by Port Authority staff in July, 1974. Major capital cost elements include transponders, interrogators, local data recording, and central processing facilities. Tasks include installation and removal of transponders, preparation of monthly statements, and handling of accounts receivable and delinquent accounts. Many choices must be made in defining the exact system. For example, would transponders be purchased by vehicle owners, or leased, or would both options be available? If leased, would a deposit be required? What agency would install or remove transponders? Who would pay? What information would be supplied on the periodic statements? Would this vary by class of user? Would all statements be issued monthly, or would variations of this period be desirable? What would be the procedure for issuing statements and receiving payment?

Answers to these questions will be developed in part through a greater understanding of the costs and benefits implicit in the choices, and in part through marketing considerations. Much of the work underway now to demonstrate a complete AVI-based toll system at the Port Authority is intended to define processing costs. The ball park estimate of total system costs is $10 per year per user, of which roughly two thirds is for the transponder and one third for mailing and account processing.

Other work to define AVI-based toll system costs is being undertaken by the New Jersey Turnpike Authority. To estimate costs of processing AVI accounts, Turnpike staff members have contacted major credit card organizations, including BankAmericard and Diner's Club. For servicing retail accounts, the general charge is approximately 6% of the gross amount. The cost of the initial credit check is $10.

The Kentucky Turnpike operates a credit system for commercial accounts, and shared their cost experience at a recent meeting of the IBTTA Research Committee. Their cost to establish an account is $7.65. Maintenance of the 500 accounts they now have is done with a partly manual system, but when the account maintenance is fully computerized the cost per account in expected to be $5 per month. This of course is for a commercial account, with each account likely to have several vehicles. There are many small truckers in the system, and the Kentucky experience with credit has been good. While there have been questions about listed trips, there has never been a refusal to pay. Delinquent accounts run about one half of one per cent.

Clearly figures such as these are pertinent to cost analysis of an AVI system, but are only parts of the picture. The parts are being assembled however, and a full analysis based on experience should be developed in the next year or two.

Further AVI Equipment Developments

The first application of an AVI system for routine operations involving the public has been implemented by the Delaware River Port Authority using an optical system supplied by the Identicon Corporation, and described in Reference 19. There are 14 lanes of Identicon equipment installed at the Walt Whitman Bridge, 13 lanes at the Ben Franklin Bridge, and 4 lanes at the Commodore Barry Bridge. The optical system is used in conjunction with automatic cash toll collection equipment. Stickers are mounted on the side windows of commuter vehicles, and contain four digits - a classification number and three digits for an expiration code representing 30 days from the date of sale. If the date is valid, the patron passes through the lane after depositing a reduced cash toll in the automatic toll collection machine. At the Walt Whitman Bridge all 14 lanes are equipped with a gate control. The Authority reports it is well pleased with the operation of the system.

In November, 1974, Fairchild Industries delivered to the U. S. Army Mobility Equipment Research and

Development Center a "brassboard" model of a microwave AVI system. Developed under contract for the Army, the Fairchild microwave system is intended immediately to identify containers. The system, described in Reference 10, uses a label (or transponder) affixed to the side of the container (or vehicle). The original label size was 4" by 5" by 0.75". But in later development, the Fairchild engineers have reduced this to 3" by 4.5" by 0.25". The system is a line of sight operation, but since the information is transmitted in the microwave band rather than the visible light band, the surface of the transponder can be made to appear part of the vehicle to which it is affixed. One example, in which the transponder is personalized with the initials JB and mounted on an Oldsmobile Toronado, is shown in the Appendix of this report.

After testing the "brassboard" model, the Army awarded a follow-on contract to Fairchild for additional units suitable for field testing. In addition, Fairchild has responded to the New Jersey Turnpike Authority's invitation to demonstrate a hand-held automatic identification device. Given its demonstrated performance characteristics, this system is likely to become an increasingly important factor in AVI.

Another microwave system, using a different design approach, was announced on August 1, 1974 by RCA (see Reference 11). Dubbed an "electronic license plate system", this could perform three functions according to Dr. Sterzer of RCA. The system could identify the vehicle, receive and transmit radio messages, and serve as a transponder in a cooperative collision avoidance radar system. While the technical feasibility of the system has been proven, so far as is known the system has not undergone extensive independant field testing.

A third noteworthy development has been sponsored by USDOT's Transportation Systems Center in Cambridge, Mass. Under contract to TSC, Hoffman Electronics developed and demonstrated a system for locating hijacked trucks. According to the USDOT news release on February 20, 1975, "The demonstration involves equipping a truck with a small transponder which responds to an ultra-high frequency signal sent from an electronic interrogator unit carried in a helicopter or other aircraft. The return signal from the transponder allows the aircraft to 'home' in on the hijacked truck and mark its position." This transponder can be placed inside containers, hiding it from potential hijackers. While not strictly an AVI system, this development illustrates the advances being made in the general identification field.

Road Pricing

Road pricing schemes differ from conventional toll road financing where the primary aim is to recoup road construction and operation costs, by having instead the primary aim of modifying road use to accord better with such public goals as promotion of mass transit. The widespread adoption of such schemes could create a significant market for AVI systems, and stimulate the wide introduction of this technology. Thus the development of road pricing is of interest in AVI development as well.

In January 1974 at the Annual Meeting of the Transportation Research Board in Washington, D.C., a full technical session was devoted to problems in road pricing. A paper on AVI was included on the program, noting the potential role of AVI in certain potential schemes for road pricing (Reference 9). The general sense of the discussion was that concern about the political feasibility of road pricing was sufficiently great as to inhibit serious testing of the potential technical solutions. And indeed, there has been relatively little development of road pricing concepts since that meeting.

Possibly the most comprehensive proposal for a road pricing scheme has been offerred by Professor Ward

Elliott of Claremont Men's College, near Los Angeles, for the Los Angeles metropolitan area. Professor Elliott's study, Reference 11, is a valuable exercise of the many considerations involved in applying road pricing on a large scale.

The most significant progress in actually applying road pricing on a large scale appears to have been made in Singapore. A special charge, equivalent to US $1.30, has been imposed on low occupancy vehicles entering the central area during the morning peak hour. This scheme is being implemented by use of stickers however, rather than AVI. Peak hour private car traffic has been cut to 25% of its previous level, and bus speeds have increased dramatically. The scheme is generally considered to be a success, and implementation during the evening peak is being considered.

In the United States, studies of road pricing are being made at the Federal level, but prospects for implementation appear remote.

Vehicle Monitoring

This technology is also closely allied to AVI, and is receiving continuing development. While AVI is suited to identify many vehicles at relatively few locations, AVM is suited to locate quite precisely relatively few vehicles. The two main approaches to AVM have been trilateration and signpost techniques. In this latter approach, short range radio transmitters along the roadside emit unique codes which are received and temporarily stored by passing vehicles equipped with the AVM hardware. When a central station desires to locate the vehicle, by automatic two-way radio the on-board equipment is triggered to rebroadcast to the central station the number of the roadside transmitter it passed most recently.

A comprehensive review of developments in AVM during the past two years is beyond the scope of this paper, but it should be noted the technology appears to be finding increasing application. The principal interest seems to be in bus fleet management. While the on-board equipment is expensive, several functions in additon to vehicle location can be performed with it, and federal funding has been available. One potential constraint is the capacity of radio channels, but new technology is being developed to increase channel capacity. The Lea Transit Compendium 1974 issue on "Bus Transit" (Reference 15) lists thirteen applications of bus monitoring. In general however, it appears there are still limitations on the performance of the technology.

Railroad Developments

As the major existing market for automatic identification technology, the railroad industry has been the primary factor in development of equipment suitable for AVI. The multi-colored stickers identifying rail cars are ubiquitous, and the optical scanners are in widespread use. However, it was reported two years ago at the "Organizing Conference on AVI" that the performance of this system was not meeting expectations. Identifications were being made only at a level of about 80%, even with attention to the problem of dirty labels.

A study of the costs and benefits of automatic identification was completed by the Southern Railway in December 1973 (Reference 13). The Southern Railway concluded it would not obtain benefits adequate to justify the cost of the system unless performance was at 90% or higher. The Southern study also concluded the benefits increased substantially as the level of readability approached 100%. Based on this study, the Southern discontinued its use of automatic identification, and urged the Association of American Railroads to seek a new generation of identification equipment capable of performing with better than 90% readability.

To evaluate the prospects for such performance, the Southern Railway staff canvassed developments in identification technology in the United States and other countries, and issued a comprehensive report in May, 1974 (Reference 14). The "Summary and Conclusions" state in part: "Substantial progress is evident in non-optical ACI development. This survey found prototype hardware whose performance exceeds that of the present optical system. All of these non-optical systems operate at wave lengths which penetrate label contaminants which cause the present system to fail. ... The tests lead us to conclude that a microwave reflection system can meet crucial AAR specification requirements that are unobtainable by the optical system. ... We believe a program could be completed in about 3 1/2 years."

Responding in part to these recommendations from the Southern Railroad, the Association of American Railroads is undertaking now a search for a second generation of identification equipment. Progress in that effort will undoubtedly benefit highway applications as well.

IBTTA Developments

The principal mechanism for pursuing AVI in the toll road industry has been the Task Force on AVI. Membership was initially concentrated in the New York and New Jersey area, with representatives from the Port Authority, the New Jersey Turnpike Authority, the Triborough Bridge and Tunnel Authority, and the New York State Thruway Authority.

In July 1974 this membership was broadened to include other toll agencies which had expressed an interest in following AVI developments. New representatives were from the Golden Gate Bridge and Highway District, the Georgia State Tollway Authority, the Pennsylvania Turnpike Commission, the Massachusetts Turnpike Authority, and the Florida Department of Transportation.

However the unsatisfactory performance of the "intermediate" generation of transponders from General Electric unquestionably dampened the momentum which had been built up in late 1973 by IBTTA and FHWA co-sponsorship of the Organizing Conference on AVI. The critical step of "going public" with AVI was deferred by the Golden Gate Bridge staff. The New Jersey Turnpike Authority management did not proceed with the joint test planned with the Port

Authority. And legal technicalities delayed the Port Authority contract with General Electric.

As a result, the Task Force did not meet again following the July 8, 1974 session at Port Authority offices, until an informal meeting was arranged in conjunction with the meeting of the IBTTA Research Committee in Denver on July 7, 1975. There were fourteen in attendance, members and non-members, with much interest evident. The major discussion concerned costs of processing AVI data and maintaining AVI accounts.

However during this time there has been a continuing strong interest in AVI developments evident through the rate of inquiries and visits received by the Port Authority and at IBTTA headquarters. It seems clear the assumption is widely shared that it is only a matter of time before AVI is applied on a broad scale.

Now with the General Electric equipment delivered to the Port Authority, extensive testing is scheduled to resume. Studies by the New Jersey Turnpike Authority indicate the level of activity on AVI for their application is likely soon to increase. The Golden Gate Bridge staff has arranged to continue testing the General Electric equipment. The Fairchild Electronics microwave system is likely to enter extensive field tests soon.

As progress is made on these fronts, there will probably be need for more frequent sessions of the Task Force. And suggestions are being made that planning should begin soon for a Second Conference on AVI. It may well be fruitful to hold such a conference during the bi-centennial year.

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DISCUSSION OF CODING FORMAT

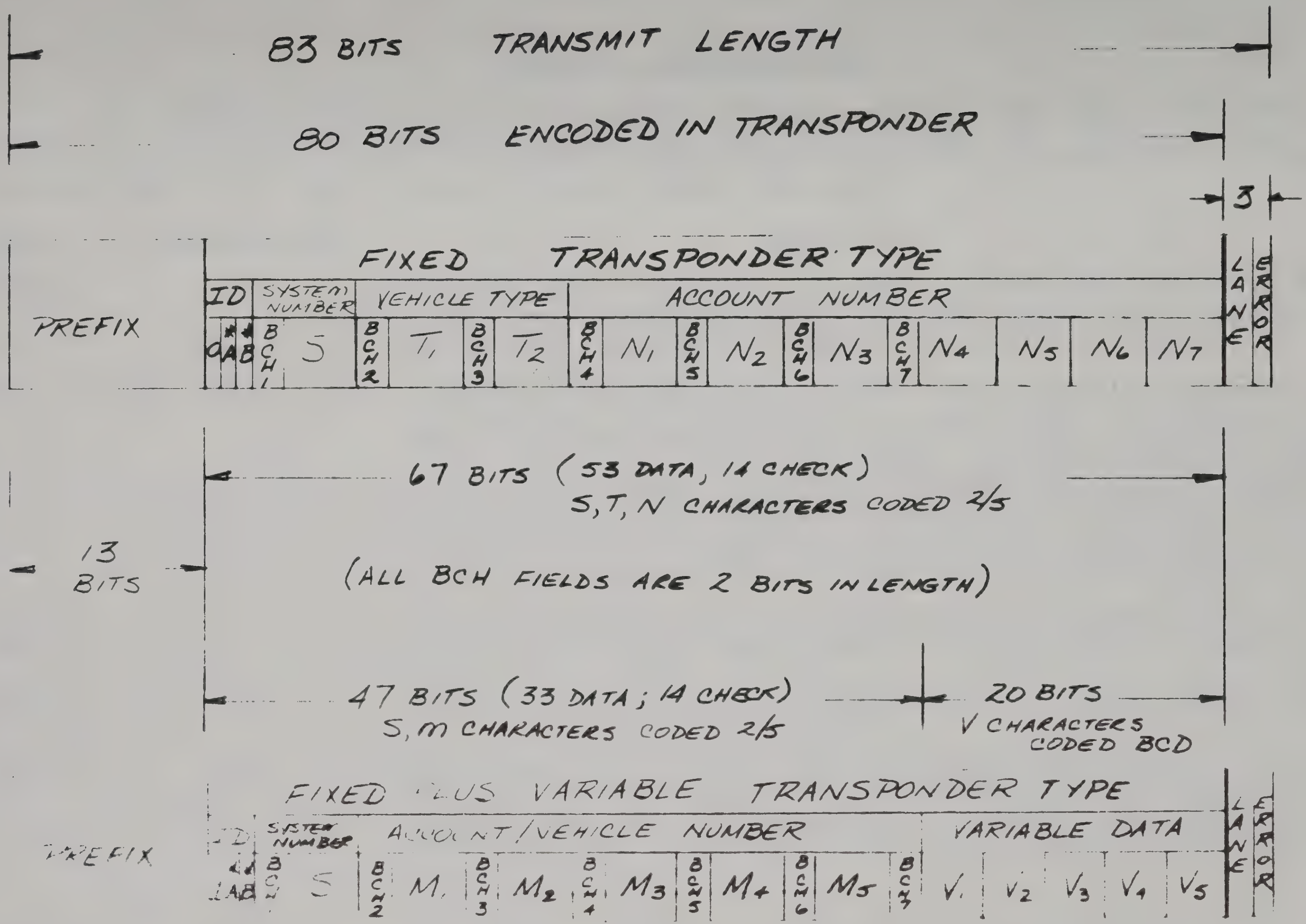
Following the basic decision to specify both the 2 out of 5 code and BCH, the manner in which the transponder's 80 bit capacity could be used most effectively was analysed. An important consideration of the design was the necessity to lead off the message with a pattern of bits which can not normally be found elsewhere in the layout. This pattern of bits (usually referred to as a prefix or start word) is used by the interrogator for both identification and synchronization purposes. If the data-carrying portion of a transponder's design were to be coded in pure binary, then the prefix length would have to exceed the length of the data-carrying pattern. This is true since any possible pattern of ones and zeros would be possible in the data. The BCH bits of the Port Authority design would have, in themselves, required a prefix length of at least 15 bits. Depending on the placement of the BCH field in relation to other non-prefix data bits, the prefix requirements could have reached as high as 20 bits. By splitting the BCH field into seven two-bit sub-fields, and by interspersing the subfields throughout the layout, the prefix length requirement was reduced to nine bits. The actual prefix length chosen is 13 bits. This allows the Port Authority design to be compatible with General Electric's intended standard for other users of the equipment. The additonal four bits provide a further protection against multiple bit errors in the body of the message, which could cause false start words to be produced.

The format that resulted and was selected is shown in the Appendix. It provides ten digits of information in the fixed version, and six digits in the fixed-plus-variable type of transponder. Five variable digits are provided in this latter type of transponder. These must be coded in BCD to insure that the unique code charateristics of the start word are not duplicated.

In addition, both transponder types provide three other identification bits. One of these is used by the interrogator to differentiate between the two types of transponders. The other two can be used to specify the manner in which the data bits are to be interpreted. They could be used to quadruple the number of distinct codes which the fixed digits are capable of carrying. Without using the additional capability, the fixed transponder version will provide for ten million codes in each of ten systems, or 100 million codes in all. In addition, each such code can be identified as one of 100 different vehicle models or types. If this feature were not desired, then a total of ten billion vehicles could be identified. As mentioned above, this number could be quadrupled if the two other identification bits were used.

The fixed plus variable transponder type can identify up to 100,000 vehicles in each of ten systems, or one million codes in all. And these numbers can be quadrupled if the two identification bits are used.

One cost of using both the 2 out of 5 code and the BCH code is to reduce the number capacity of the transponder. If the prefix length were to be 12 rather than 13 bits, and if only the 2 out of 5 code were to be used, then the maximum number of vehicles which could be identified would be 40 trillion.



* THREE BIT FIELD DESCRIBING TRANSPONDER TYPE (FIRST BIT) AND MESSAGE TYPE WITHIN TRANSPONDER TYPE

BCH - CODE USED IS A MODIFIED 127,113,2

FIXED TRANSPONDERS - 53 DATA BITS PLUS 60 LEADING FICTICIOUS ZERO

FIXED PLUS VARIABLE - 33 DATA BITS (FROM FIXED PORTION) PLUS 80 LEADING FICTITIOUS ZERO BITS

EXHIBIT A

80 Bit AVI Transponder Encodings

Exhibit A - Explanatory Notes

The comparative layouts of the two basic 80 bit transponder types are shown above. The layouts describe not only the 80 bits encoded in the transponder itself (twenty of which are introduced through the use of external devices in the Fixed Plus Variable type) but also the three bits appended to the encodings by the interrogator at its time of transmission to the computer and printer.

Field	Transponder Type	Utilization
Prefix	Both	A predetermined string of bits (usually all ones followed by a zero) which is longer than the pattern of similar bits which could naturally occur in the message body. It is used to identify the beginning of a message.
ID	Both	A three bit field which 1) through the use of its first bit, identifies the type of transponder, i.e., fixed versus fixed plus variable, 2) contains two spare bits (*A and *B) which can be used in the future to identify alternate utilizations of the remaining data fields. For example, the fixed transponder layout shown breaks the ten available data digits into three sub-divisions: System Number, Vehicle Type and Account Number. It has an ID field of 000. An ID field of 001 might be selected in the future to identify an entirely different utilization of these digits within the same basic 80 bit Fixed transponder layout.
System Number (S)	Both	Designed to allow for the identification of ten independent series of account numbers. This could be used to identify different AVI issuing agencies.
Vehicle Type (T)	Fixed	Allows (if desired) for the identification of the vehicle to which the transponder has been assigned by type.
Account Number (N)	Fixed	These seven decimal digits allow for the distinct identification of ten million vehicles within each vehicle type (T). For example, if the vehicle type for passe ger cars were chosen as the series 00-49, 500 million cars could be uniquely identified. Fifty other vehicle types could be further identified with each havin a capacity of ten million codes.
Account/Vehicle Number (M)	Fixed Plus Variable	Essentially the same as the Account Number in the Fixed Transponder but limited to a total of 100,000 unique identifications per system number.
Variable Data (V)	Fixed Plus Variable	Five digits of variable data entered as Binary Coded Decimal. The *A and *B bits of the ID could be used to define the type of data being entered here.

J
B

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